Introduction

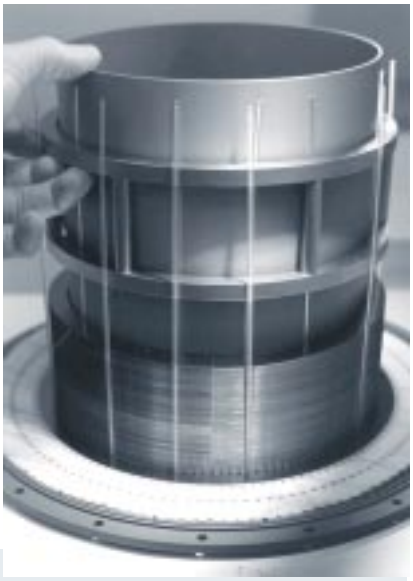
Year In Review

The NHMFL 1997 Annual Report is being published in two volumes for the first time this year because of the expanding number of research reports. Volume I will contain only user research reports and research-related sections. Volume II will be a progress report of laboratory program areas and will be published in late summer to coincide with the annual NSF Site Review.

Dirac II Series of experiments at Los Alamos.

The year of 1997 was a very productive period, as the National High Magnetic Field Laboratory's (NHMFL) focus shifted from facility and infrastructure development to enhancing research opportunities and user activities. The In-House Research Program, a requirement of the contract with the National Science Foundation (NSF), was fully and successfully implemented, and the second round of funding proposals was awarded to researchers. The user communities at all three sites continued to flourish and grow in record numbers. The Ultra-High B/T Facility at the University of Florida was opened to outside users and exciting data were obtained at temperatures below 0.5 μK and at 15.5 T. At the Pulsed Field Facility at Los Alamos, the new power supplies were installed and successfully tested for the quasi-continuous 60 T magnet that has been assembled and awaits commissioning. The NHMFL co-sponsored the second round of the Dirac Series that produced four flux compression shots at 850 T at Los Alamos. The world's two newest and largest magnet laboratories, NHMFL and the Japanese National Research Institute for Metals' (NRIM) magnet laboratory, entered into a formal program of cooperation. The international agreement will facilitate new scientific exchanges, advance user research facilities, and drive important new technologies. The first high technology company to locate in Tallahassee because of the laboratory arrived early in the year. EURUS Technologies, Inc.® produces high temperature superconducting current leads and superconducting tape, and its close proximity to the NHMFL fosters numerous interactions between the two organizations and personnel.

The Magnet Science and Technology group achieved several milestones in the fabrication of new magnet systems for external organizations. A 30 T resistive magnet was delivered to the Japanese Magnet Laboratory in Tsukuba. A prototype resistive magnet was developed for NASA that may someday be deployed on the International Space Station to grow crystals in zero gravity. The pulsed magnet group designed



Coil stacking for 0.14 T, 184 mm bore, 3 kW resistive magnet for NASA.

the next generation of capacitive pulsed magnets for Los Alamos. They reach higher field and are cooled down between shots in half the time. The pulsed group also fabricated several state-of-the-art pulsed magnet systems for other national laboratories and universities.

NHMFL Chief Scientist Robert Schrieffer.

The laboratory hosted half a dozen international conferences at the three sites, including the first Robert Schrieffer Tutorial Series at Los Alamos and the 75th Anniversary Symposium for Raymond Andrew at the University of Florida. Three international conferences held at the main facility in Tallahassee also introduced over three hundred potential users to the NHMFL — *First North American FT-ICR Mass Spectrometry Conference; Physics of Manganites, Ruthenates, & Related Materials;* and *Eighth U.S./Japan Workshop on High Temperature Superconductors*.

Under the direction of the laboratory's K-12 education program, nine Florida teachers joined local students and in-house scientists to develop a new standards-based interdisciplinary curriculum package to study magnets and magnetism. After the magnetism instructional units are field tested in 200 Florida middle schools, the unit will be marketed nationwide. Educational outreach programs to excite and challenge K-12 students about science and technology have become a year-round effort at the laboratory with over 14,000 students participating in these programs. Each October the NHMFL hosts an open house to enhance public awareness of science and technology, and this year's event attracted a huge crowd of over 3,500 people.

The 1997 Open House attracted over 3,500 visitors.

The NHMFL was the subject of a cover story in *Chemical and Engineering News*, and NHMFL researchers appeared in special stories for *CNN's Future Watch* and *Discovery's World of Wonder*. The Australian science program *Quantum* produced a half-hour special on the Dirac II Series and the research was featured in *The Economist*.

User Programs

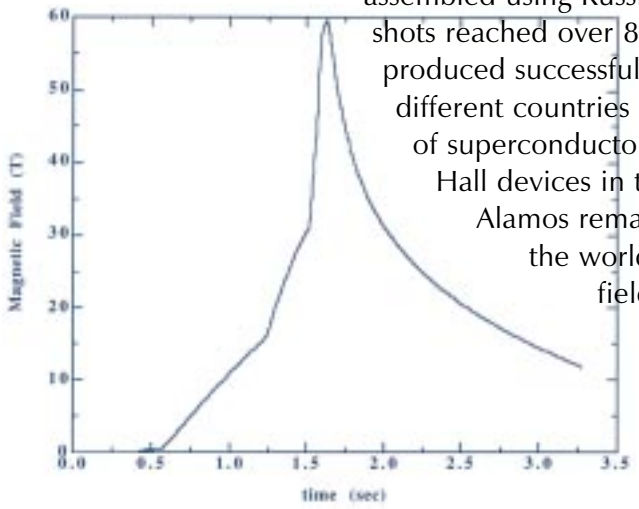
The NHMFL user program continues to grow as new users request magnet time. At the continuous field facility, researchers spent a total of 1,438 magnet-days on the resistive and

superconducting magnets. At the pulsed field facility, researchers spent a total of 720 magnet-days on the pulsed magnets and the superconducting magnet. The *1997 NHMFL Annual Report* contains 255 research reports as a result of these wide-ranging activities. The NHMFL sponsored a booth at the APS March Meeting, and it was the first time that a national laboratory had ever participated in the APS meeting trade show activities. The interest in the NHMFL displays was so significant that the laboratory has decided to expand the display for this year's meeting. The laboratory has also been requested to participate in a similar manner in other international meetings. Working in close consultation with the Users' Committee, both the Tallahassee and Los Alamos facilities added numerous instruments and techniques in response to user requests. The Visitors Program has become an important and valuable source for new instrumentation development, since researchers are able to stay for extended periods. Three new state-funded research scientist positions were filled in Tallahassee to support the users program in far-infrared, visible optics, and magnetometry. An additional research scientist was hired to assist the growing condensed matter physics and NMR user community. The Ultra-High B/T Facility at the University of Florida came on-line later in the year and user interest from the United States and Europe has been considerable. Users will be able to explore new phenomena that require both high fields and very low temperatures simultaneously. This is the only facility worldwide to have such unique capabilities.

Looking into the maw of the 60 T quasi-continuous magnet at Los Alamos.

At the NHMFL Pulsed Field Facility at Los Alamos, all seven of the power supplies were tested and commissioned. The 60 T quasi-continuous magnet was assembled, installed in its dewar, and will be commissioned soon for user research. Preliminary testing has demonstrated the utility of the 60 T system. For the second consecutive year, the NHMFL co-sponsored the Dirac Series of flux compression shots providing researchers access to the most powerful magnets ever assembled using Russian generators. The series of four shots reached over 850 T for millionths of a second and produced successful data. Over twenty scientists from six different countries probed the unusual electronic states of superconductors, semiconductors, and quantum Hall devices in these ultra-high magnetic fields. Los Alamos remains the only magnet laboratory in the world offering general user access to fields up to 1000 T.

50 T pulsed field magnet coils, with small test coils in the background.



Initial test pulse of 60 T quasi-continuous magnet.

The Center for Interdisciplinary Magnetic Resonance (CIMAR) added to its user inventory a Magnex Scientific superconducting NMR magnet at 19.6 T, 31 mm bore. The EMR program experienced increasing user and visitor activity on the highest homogeneity magnet built for EMR, 15/17 T with an inhomogeneity of 1 ppm for a 10 mm DSV. The FT-ICR program had seventy-seven researchers use the facility, a 400 percent increase over the previous year. A microelectrospray source was constructed and interfaced with the 9.4 T FT-ICR mass spectrometer. This system separated and detected a three-component peptide mixture in artificial cerebrospinal fluid with each peptide present at only 500 attomoles/microliter. The 3 T whole-body magnet system at the University of Florida Brain Institute/VA Hospital is in service and is being used in support of several NIH-funded projects. The advantages of this system over most other whole body systems include spatial resolution of 25 microns/pixel and rapid image acquisition rates of 10 per second.

3 T whole-body imaging system at the University of Florida.

The NHMFL moved forward with the suggestions made by the 1996 NSF Review Committee to seek input from the magnetic resonance community in establishing a new model for support of user activities within the United States. The NHMFL has proposed and discussed with the NSF the establishment of a National Magnetic Resonance Collaboratorium in response to the science and technology opportunities in this area. The Collaboratorium would include distributed centers strategically located across the country and connected by the Internet. This distributed user facility would provide remote access for users and would pursue a science and technology agenda critical to advancing magnetic resonance in the biology and chemistry areas. A national Planning Group has been established, and this group is preparing for a national conference to be held in Washington, D.C., in January, 1998. The purpose of the conference will be to define more clearly the scientific opportunities and technological challenges which require extremely high field nuclear magnetic resonance.

National Magnetic Resonance Collaboratorium

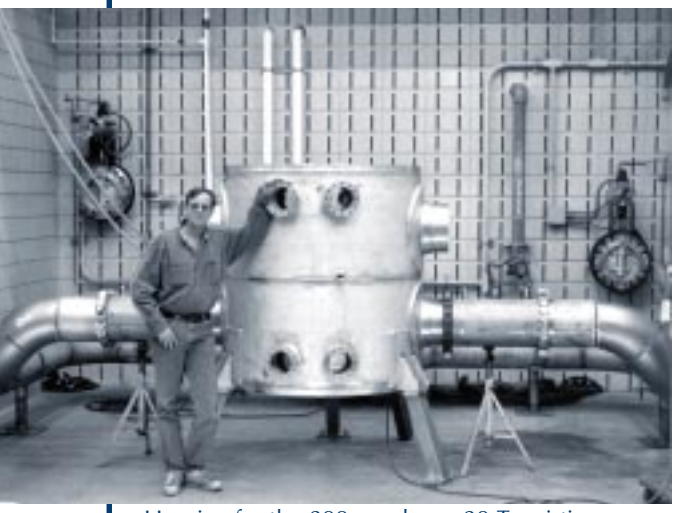
Magnet Science & Technology Program

As the Magnet Science and Technology (MS&T) program matures, it is playing an increasing role in the supply of services to the NHMFL user community. MS&T user services appear in different forms including: fabrication of magnets and other kinds of hardware for users; providing specialized measurement techniques for technology development projects; and carrying out analysis and review for user proposed projects. Maturity of the laboratory and the MS&T program has allowed Deputy Director Hans Schneider-Muntau to relinquish his dual leadership duties as the Director of MS&T and devote his energies to forging new international and private sector collaborations in magnet-related technologies. Under Dr. Schneider-Muntau's extraordinary leadership, an outstanding magnet development program has been established at the NHMFL, with its fine track record of engineering design excellence, innovation, and three world records for continuous field magnets. Dr. Steven Van Sciver has assumed the leadership reins of the MS&T program. Dr. Van Sciver is a leading expert in cryogenics, an outstanding engineer and professor, and an excellent program manager.

Over the year, MS&T achieved a number of major milestones and several highlights are listed below.

- Completion and installation of a 30 T resistive magnet under contract for the Tsukuba Magnet Laboratory operated by the Japanese National Research Institute for Metals (NRIM).

- The 200 mm bore, 20 T resistive magnet, which is a joint design project with the Grenoble magnet laboratory, neared completion. The design for an insert cryostat was also completed.



Housing for the 200 mm bore, 20 T resistive magnet.

- The Keck 25 T, 52 mm bore high homogeneity resistive magnet reached the final stages of completion. This magnet is funded by the NHMFL and a grant from the Keck Foundation and will be equipped with new specialized instruments for NMR, EMR, and ICR.

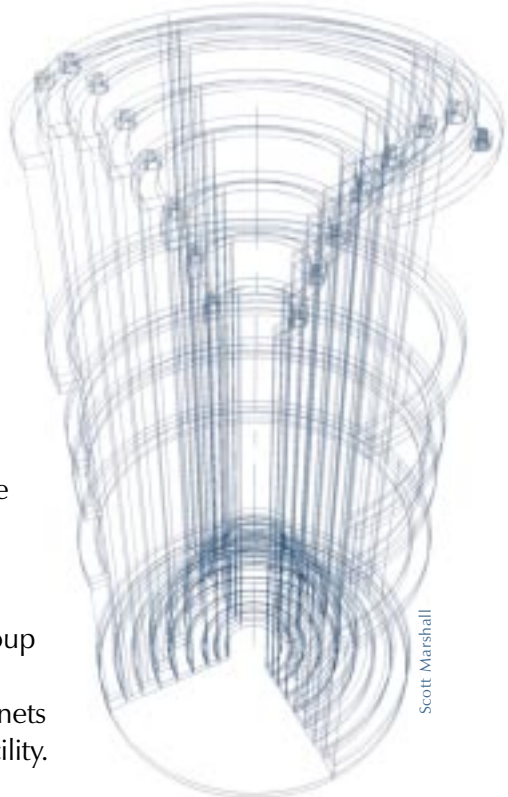
80 MVA power converters at Los Alamos (total capacity 560 MVA).

- The 45 T hybrid magnet also made significant progress with all superconducting coils being wound and assembly well underway. Design of the resistive insert is also nearing completion.

- A major milestone in the 900 MHz project was completed with the issuance of the final design specification for the magnet. The Nb_3Sn wire has been ordered and individual components are being fabricated.

- A prototype resistive magnet was designed and built by the NHMFL for NASA. The 0.14 T, 184 mm bore, 3 kW magnet could be used for growing crystals on the International Space Station.

- The Pulse Magnet Group is upgrading the capacitive driven magnets for the LANL users facility. The 24 mm bore user magnets will go from 50 T to 60 T, and the 15 mm bore from 60 T to 70 T. This next generation of capacitive pulsed magnets achieved all



Scott Marshall

Schematic of the 900 MHz magnet.

their expected design specification and will give the NHMFL Pulsed Field Facility the finest pulsed magnets available in the world.

- The 60 T quasi-continuous magnet at LANL is undergoing testing and will be commissioned in the near future. Four more 80 MVA power converters were commissioned in June, 1997, bringing the total number of 80 MVA converters to seven.

- The joint 100 T pulse magnet project with the Department of Energy is exploring conceptual design options and has pursued a focused materials evaluation program to define the materials parameters for this extremely challenging system.

- The Pulse Magnet Group built a variety of unique capacitor driven pulsed magnets for the X-ray Radiography Group at Sandia National Laboratories; the Laboratory for Plasma Science at the University of Wisconsin; the Physics Department of Harvard University; and the Australian National Pulsed Magnet Laboratory in Sydney.

- The High Temperature Superconducting (HTS) Magnets and Materials Group completed and tested a 1.2 T, 50 mm outer diameter high Tc superconducting coil in a background field of 17 T. The conductor was provided by Oxford Superconductor Technologies. The group collaborates extensively with industry in the development of this technology.

- The Materials Development and Characterization Group performed a variety of tests on a collaborative basis. A few examples carried out during the year include: testing HTS current leads at 13,000 amp. for EURUS Technologies; tensile testing of aluminum alloy for the FSU Nuclear Physics Group; resistivity ratio measurements on braided cable for Babcock and Wilcox; and strength characterization work of high strength/high conductivity wires for Brush-Wellman.

EURUS Technologies superconducting leads.

NHMFL In-House Research Program

The first two years of the In-House Research Program have been completed under the very capable leadership of Program Director Dr. John Graybeal and Chief Scientist Dr. J. Robert Schrieffer. Directorship of the In-House Research Program rotates every two years among leading researchers at each of the three sites. Beginning in 1998, the leadership of the program will shift to National Academy of Science Member, Prof. Zachary Fisk. It is important to note that the In-House Research Program seeks to enhance collaborations between internal and external researchers, to support bold but risky experiments that will advance the laboratory, and to seed the research of new and younger faculty and staff. The program also has enhanced the cooperation of researchers among the three participating institutions and the external users community.

The first fifteen funded proposals are now in their second and final year of support, and some of the initial results are contained in Chapter 1, Research Reports. The second solicitation produced 28 proposals: 10 in magnetic resonance; 10 in condensed matter physics; and 8 in materials science and engineering. After two external reviews, seven proposals were awarded funding. More information about these projects is in Chapter 3 of this report.

As a part of the long-term strategic planning within the laboratory, MS&T will initiate three new study projects to develop conceptual designs and assess the costs for new opportunities and possible consideration in the future. These design studies include the development of (1) a modulation and compensation coil to further the scientific utility of the 60 T quasi-continuous magnet; (2) a single-turn destructive pulsed magnet system that would provide user access to 200+ T for microseconds in a 10 mm bore and save the sample; and (3) a 1.5 GHz (35 T) series connected hybrid that will provide greater stability and homogeneity for magnetic resonance studies and at the same time allow more cost effective operation than is possible with existing powered magnet systems.

Outreach Activities: Education and Collaborations

Education ■ Educational outreach activities for grades K-12 have expanded and matured significantly under the first year's direction of a science educator, Dr. Sam Spiegel. Over 4,000 K-12 students toured the laboratory and participated in lectures and demonstrations during the year. Another 10,000 students throughout the State of Florida participated in the NHMFL's outreach program, which teaches the principals of magnetism through its effects on our daily lives. Some students came from considerable distances, for example, the laboratory hosted a group of high school students from the Newport News, Virginia, area, who were affiliated with a program at Hampton University (a historically black university).

The NHMFL recognized the need for improved magnetism curriculum materials in the early 1990's, when the laboratory was developing a traveling exhibit on electricity and magnetism with the Museum of Science and Industry in Tampa, Florida. With the grant support of the Florida Department of Education, two full-time educators and nine master teachers joined students and NHMFL scientists to develop a new standards-based interdisciplinary curriculum package to study magnets, magnetism, and related concepts. The new magnetism curriculum, *MagLab: Alpha*, was released this fall to 200 Florida middle school classrooms, and negotiations are underway to facilitate nationwide distribution. The activity-based materials allow students to explore a variety of scientific concepts that lead to further discovery and allow both the teacher and student to assess and evaluate student learning. The collaborative nature of the materials models how science is done in real-world research institutions.

Reactions to *MagLab: Alpha* from Florida educators have been very positive:

"MagLab: Alpha is a fantastic program which encourages student-centered learning. The program involves students in the learning process where they are developing and using problem-solving skills. The program also allows the teacher to be a learner as well as a facilitator."

Educator, Lake County

"This type of consortium with the NHMFL is the type of help that we teachers in the state need to promote science instruction in the schools. I am sure that there are other such possibilities available. Please continue to promote such activities."

Educator, Dade County

The NHMFL's annual open house, in its fourth year, has always been a popular attraction for surrounding communities, but this year's event brought a huge crowd of 3,568 people to the Tallahassee facility. Almost seventy-five percent of these visitors were making their first trip to the laboratory; almost half of them were K-12 students; and a large number were elderly. Every aspect of the laboratory featured exciting demonstrations, hands-on activities, displays, and videos. These efforts were all designed to explain magnetism and the importance of science and technology to our quality of life, to regional economic development, and to the competitive position of the United States.

For the fifth consecutive year, the laboratory sponsored a summer research internship program for women and minority undergraduate students. The number of applicants to this program increases annually because of recruiting assistance from the Florida-Georgia Alliance for Minority Participation (AMP). This year all but two of the eighteen undergraduate students were female. One of the intern's research in condensed matter physics will result in a published paper. A student from the previous year recently wrote:

"In great part, thanks to the opportunity given to me last summer and your letter of recommendation, I have been accepted in a Ph.D. program at the University of Delaware and am currently working on my own research project here at Argonne National Lab. The summer internship last year helped me a great deal in building my own picture of the physics field and deciding on the direction in which I would like to continue to pursue in my career."

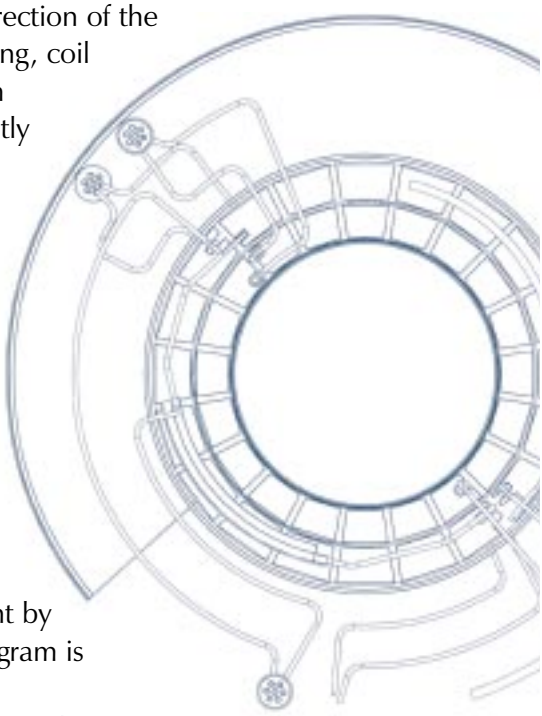
The NHMFL educational activities are not just limited to K-12 and undergraduate students. For the second summer, the NHMFL participated in the NSF Chautauqua Short Course Program for college teachers. This year's course was entitled "Who Needs Magnetic Fields" and provided participants with the choice of three research areas:

Physics, Engineering, and Biology & Chemistry. The NHMFL's partnerships with regional vocational schools have also expanded educational opportunities for vocational-technology students at the laboratory.

EURUS high temperature superconducting tape.

Collaborations ■
A collaborative culture has developed within the NHMFL that is evidenced by the increasing number of private sector companies and other organizations that have contacted the laboratory for its expertise and partnering on proposals. The laboratory is most pleased that a recent CRADA with EURUS Technologies, Inc., has resulted in the company moving its headquarters to Innovation Park, Tallahassee, across the street from the NHMFL. EURUS produces high temperature superconducting current leads; is pursuing other opportunities in the application of HTS technology; and has entered into a three-year, co-development, and testing program with the NHMFL. Recently EURUS announced the acquisition of Plastronic Inc., the U.S. Midwest developer and manufacturer of high temperature superconducting (HTS) electric conductor tape. The acquisition capitalizes on a number of new and exciting discoveries related to second-generation HTS products, as announced by the Department of Energy's 1997 Annual Peer Review. We look forward to a long-standing and productive relationship with this growing high-tech company. It represents the type of industry that can and should be located in a small radius of the NHMFL.

The 45 T Hybrid project continues to foster collaborative activities and technology transfer opportunities with U.S. industry, especially as it relates to large magnet systems that will be required for the fusion program and superconducting magnetic energy storage (SMES) devices. The partnership with Intermagnetics General Corp. (IGC) on the hybrid magnet has resulted in new, unique manufacturing capabilities for the United States in the production of world-record lengths of high quality superconducting cable-in-conduit conductors. IGC has also had the primary responsibility, under the direction of the NHMFL, for the conductor jacketing, coil winding, and termination. Everson Electric and the NHMFL have jointly developed and implemented the insulation and impregnation procedures for the hybrid's double pancake superconducting coils. Everson Electric has also instituted a comprehensive quality control system for these pancake coils.

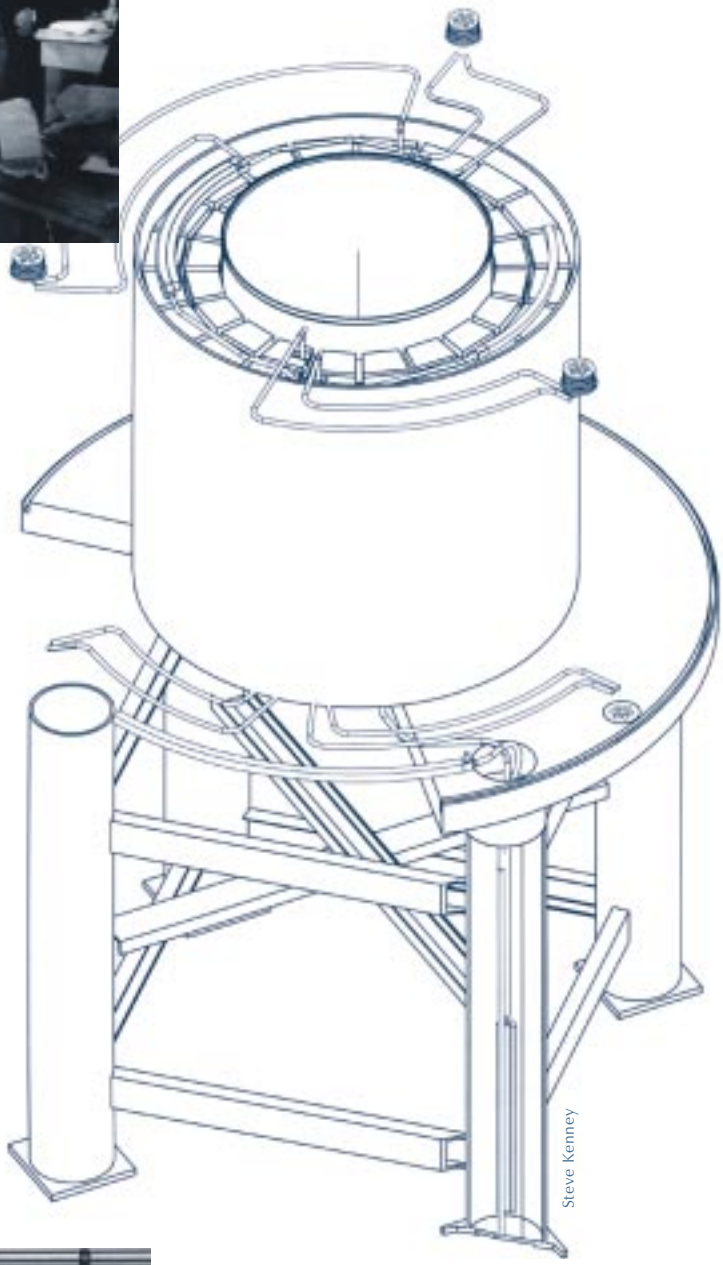


IGC has also taken a significant role in the development of the ultra wide bore 900 MHz NMR magnet system under development by the NHMFL. This cooperative program is

Coil for 45 T Hybrid being wound at Everson Electric.

IGC 45 T Hybrid development team (left).

Schematic of the 45 T Hybrid (below and page x), showing cryogenic leads and connections inside the support infrastructure.



Steve Kenney

designed to help U.S. industry obtain the technology needed to compete in high field NMR magnets. Not a single NMR spectrometer magnet over 500 MHz is American-manufactured. IGC has recognized the value of the technology transfer from the NHMFL with a $1 million commitment to the 900 MHz project.

The Department of Navy is using the NHMFL as its official test site for a SMES device developed by Westinghouse Corp. Since the Navy's contract with Westinghouse expired in late July, the NHMFL is finishing those components of the system before testing can be undertaken. The Navy is interested in using the laboratory's unique testing facilities and its engineering expertise in building large-scale magnet systems such as the 45 T hybrid magnet. Upon completion of the tests, the Navy will leave behind their magnet-related equipment for use by the NHMFL as a large coil and conductor test facility.

John Miller, head of the NHMFL's Hybrid project, with the Navy's SMES magnet.

Building on several years of productive scientific exchanges of faculty, conferences, and technology, the NHMFL signed an agreement with the NRIM's National Magnet Laboratory in Tsukuba, Japan. The international agreement formalizes the beneficial exchanges between the two laboratories that have already resulted in the

Awards, Honors, and Services

A more comprehensive listing of these distinguished achievements can be found in Appendix C of this report. The following, however, is a sampling of the year's accomplishments.

- NHMFL Director Jack Crow was invited to serve as a member of the Department of Energy Basic Sciences Advisory Committee.
- Vladimir Dobrosavljevic of the NHMFL Condensed Matter group received an Alfred P. Sloan Fellowship.
- Lev P. Gor'kov, NHMFL program director and professor, was named a Fellow to the American Physical Society.
- University of Florida theorist Pierre Ramond was elected president of the Aspen Center for Physics.
- Alan Marshall, acting director of CIMAR, received an NSF Two-Year Creativity Award and the 1997 Maurice F. Hasler Award.
- Dr. Pierre Sikivie of the University of Florida received the Jesse Beams Medal from the Southeastern Section of the American Physical Society.
- Director of MS&T Steven Van Sciver was named Distinguished Research Professor from Florida State University.
- Nineteen NHMFL-affiliated graduate students at Florida State University and the University of Florida earned Ph.D.s in Physics, Chemistry, Engineering, and Science Education during 1997.

NHMFL building a 33 T magnet for its facility using NRIM's Cu-Ag material for the innermost coil, and the design and construction at the NHMFL of a 30 T magnet for the NRIM laboratory. Partnership with the Grenoble Magnet Laboratory has led to the co-development of the 20 T, 200 mm bore magnet. The National Pulse Magnet Laboratory at the University of New South Wales in Sydney, Australia, commissioned two 50 T coils using a new NHMFL design that features replacing the carbon composite outer reinforcement shell of the magnet with a custom machined steel shell. This new configuration has the advantage of reducing the cooling time after a pulse by 50 percent, thus increasing the capacity of the laboratory to meet the needs of the user community.

NHMFL Director Jack Crow announces collaboration agreement with NRIM's National Magnetic Laboratory in Japan.

The NHMFL has had the good fortune to have had thirty-seven postdoctoral fellows associated with its research, engineering, and users programs during the past year. Not only has this program provided opportunities for more independent research for these bright young scientists, but it also seeds the next generation of users in high magnetic fields. Several of these postdocs have moved on to new assistant professorships at other institutions and others have accepted positions with industry. The NHMFL would like to expand its research opportunities for postdocs with an international exchange program. Such a program would broaden the exposure of NHMFL facilities to the international community and vice versa. The NHMFL is pursuing the establishment of a European-U.S. Scientific Foundation that would support European postdocs at the NHMFL and U.S. postdocs in Europe. Funding for a similar program with Japan is also being pursued.

The NHMFL is pleased to present the research activities of the laboratory in this volume of the annual report. Program activities will be reported in Volume 2, to be published in late summer 1998. ■